COMMISSIONING OF THE RCNP RING CYCLOTRON

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ABSTRACT

The construction of the ring cyclotron was started in August 1987. On October 12th 1991 the first beam was injected into the ring cyclotron. Many improvements were made for the initial trouble of operation. On December 20th the first extracted beam of 300 MeV protons was obtained. Various test experiments were done with 300 MeV polarized proton beam for a high precision magnetic spectrograph and a neutron TOF facility.

1. INTRODUCTION

The Research Center for Nuclear Physics was funded in 1971, as a national user facility. A K=140 AVF cyclotron[1] and precise experimental apparatus were used during a decade by many researchers in Japan and abroad. After intensive design study of new facility, "RCNP Cyclotron Cascade Project"[2,3] was proposed in 1985, to extend the high precision studies into energy region above threshold energy of pion production. The main components

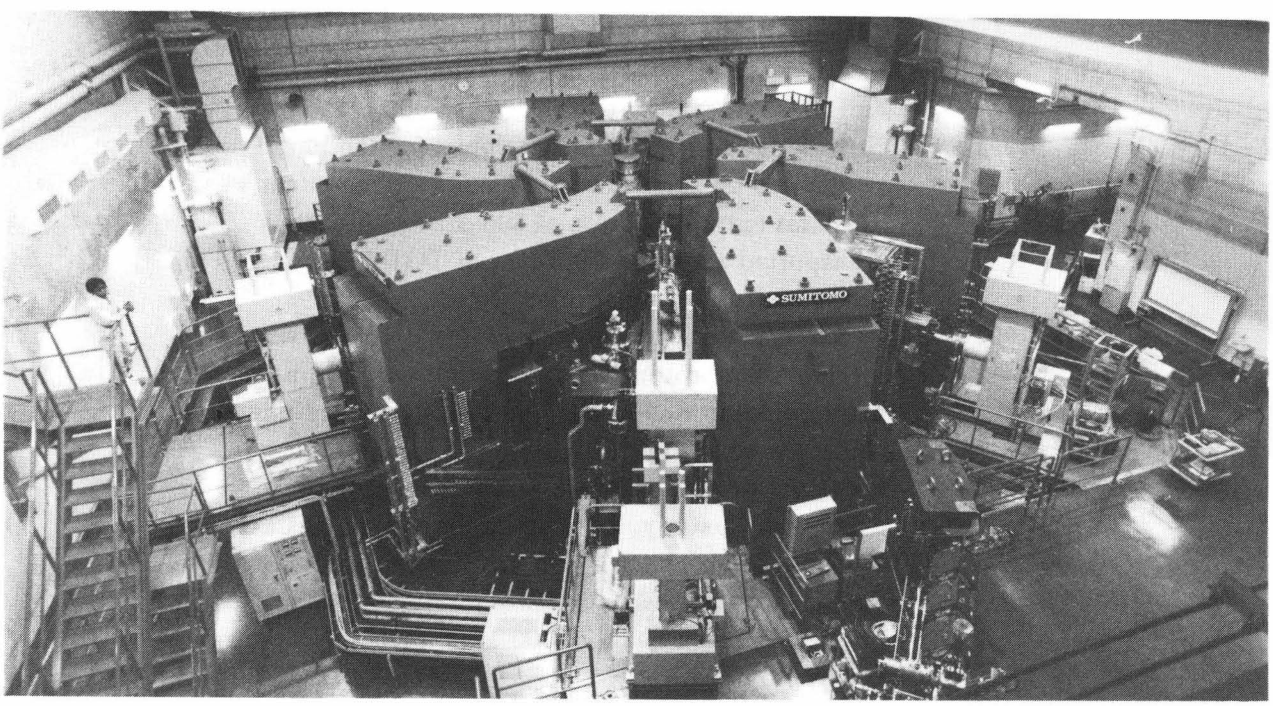


Fig. 1. Photograph of the RCNP ring cyclotron.

of the new facility are a six separated spiral sector cyclotron (ring cyclotron) and beam circulation ring linked to high precision dual magnetic spectrograph, a neutron TOF facility with a 100 m neutron flight tunnel and a heavy ion secondary beam facility.

In 1986 the proposal was accepted and the four years cyclotron construction contract was made with manufacturer in August 1987. Installation of the ring cyclotron was started in February 1990, immediately after finish of the Ring Cyclotron Hall. Figure 1 shows the photograph of the ring cyclotron. On December 20th the first extracted beam of 300 MeV protons was obtained. The chronology of construction and commissioning is shown in Table 1. Experimental study with the AVF cyclotron was continued during the construction and the commissioning. Now main effort for experimental study is made with new facility.

Table 1
Chronology of construction and commissioning

Aug.	1987	The cyclotron construction contract was made.
Nov.	1987	Readjustment of the land for the ring cyclotron building was started.
Feb.	1990	Installation of the ring cyclotron was started.
Aug.	1990	Utilities of the new facility was finished.
Apr.	1991	Accumulation of the magnetic field data of the ring cyclotron during 4 months was performed.
Sept.	1991	New beam injection line, beam buncher and beam pulser were tested. Vacuum leak-test of the ring cyclotron was finished.
Oct.	1991	The first beam was injected into the ring cyclotron and successfully pass through the injection elements to beam stopper following the flat-topping cavity.
Nov.	1991	Acceleration cavity voltage of 400 kV was achieved and proton beam accelerated up to 300 MeV.
Dec.	1991	New signal amplifier was developed for the phase probe. Correction on the deflector position drive system was made. The first extracted beam of 300 MeV proton was transported to the beam dump of TOF facility and one of the high precision spectrograph.
Mar.	1992	Acceleration cavity voltage of 510 kV was achieved for 400 MeV proton beam acceleration. Proton beam accelerated up to 400 MeV. Preliminary experimental studies were started with 300 MeV proton beams.
Apr.	1992	Polarized proton beam was transported for the experimental study. Single turn extraction was achieved by using beam buncher and flat-topping cavity.
May	1992	A 500p sec time resolution was obtained for the polarized proton beam of 300 MeV with a 1/4 pulsing of injection beam.

The new systems of the ring cyclotron had been tested and many improvements were made for the initial trouble of operation. Improvement of capability on the high voltage vacuum feed-through of deflectors and the power supply of second magnetic inflection channel will be made by replacement in August. The magnet system, the RF system, the vacuum system, the beam diagnostic system and the computer control system are reported elsewhere in these proceedings. These systems work well now and efforts being continued to improve beam quality, intensity and stability of the ring cyclotron.

The ring cyclotron is energy quadrupler of the RCNP AVF cyclotron. Protons and alpha particles can be accelerated up to 400 MeV. The K value for light-heavy ions acceleration is 400. Plan view of the ring cyclotron is shown in Fig. 2. Three single gap acceleration cavities are used in the ring cyclotron. Frequency range of the cavity is 30~52 MHz and harmonic numbers of acceleration is 6, 10, 12 and 18. An additional single gap cavity is used for flat-topping with 3rd harmonic of acceleration frequency to get good energy resolution and wide phase acceptance. The phase acceptance is 20° for

A 180°-single-dee acceleration cavity is used in the RCNP AVF cyclotron. The frequency range of the cavity is 5.5~19.5 MHz, and fundamental and

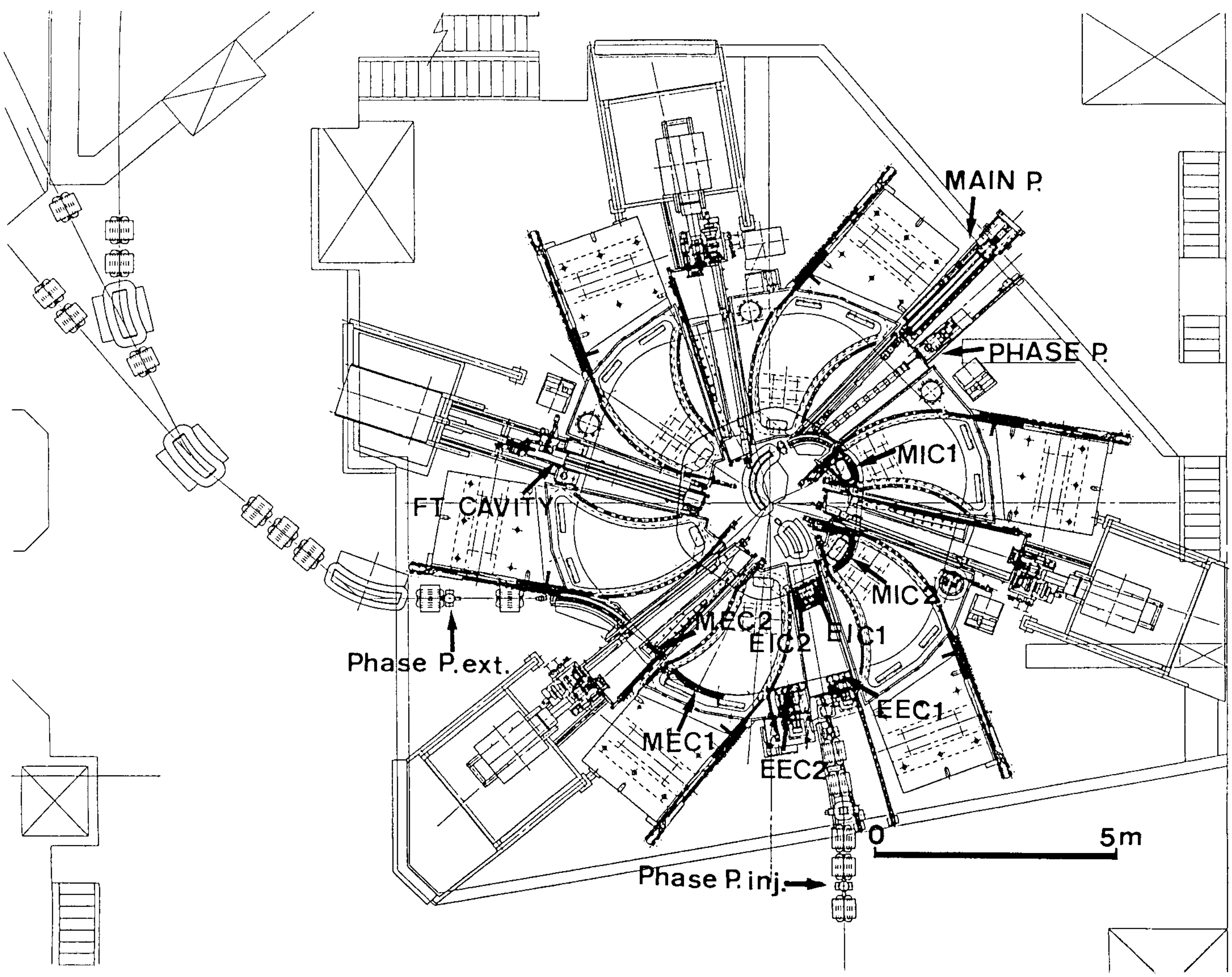


Fig. 2. Plan view of the ring cyclotron.

3rd harmonic acceleration modes are used. Figure 3 shows relation between orbital frequencies and acceleration frequencies in the AVF cyclotron and the ring cyclotron for various ions and energies.

The phase acceptance of the ring cyclotron on the acceleration frequency of the AVF cyclotron is 7° and 4°, since the ratio of acceleration frequency of the ring cyclotron to that of the AVF cyclotron is 3 and 5 for proton and alpha, respectively. The characteristics of the cyclotrons are given in Table 2.

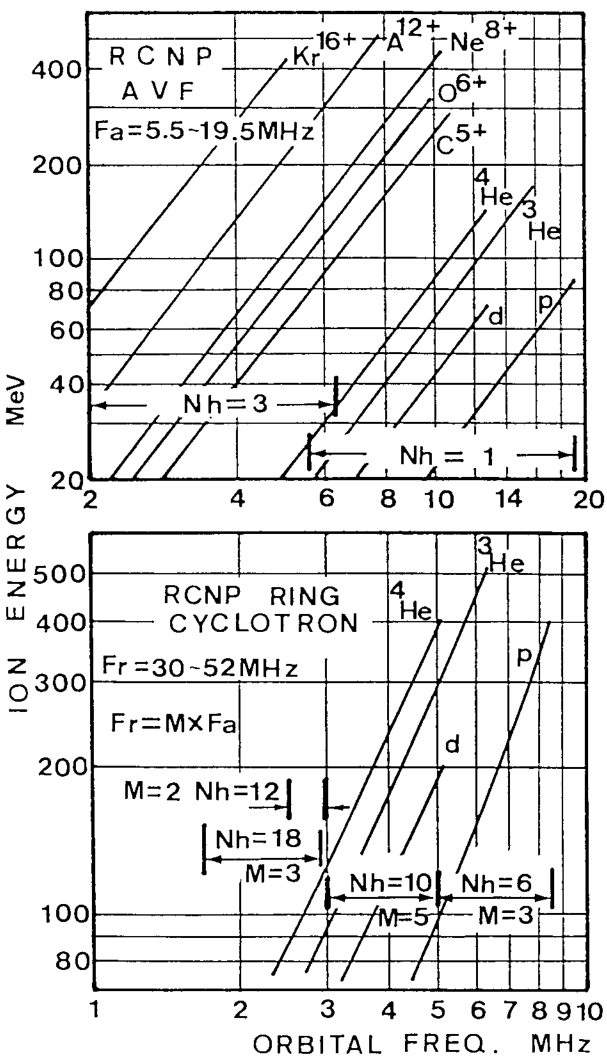


Fig. 3. Orbital frequencies, acceleration frequencies (Fa& Fr) and harmonic numbers of acceleration (Nh) in the RCNP AVF cyclotron and the RCNP ring cyclotron for various ions and energies. M is ratio of the acceleration frequency of the ring cyclotron to the AVF cyclotron.

Table 2

Characteristics of cyclotrons

	Injector Cyclotron	Ring Cyclotron
No. of sector magnets	3	6
Sector angle	max 52°	22~27.5°
Injection radius(cm)		200
Extraction radius(cm)	100	404
Magnet gap(cm)	20.7 min	6.0
Max. Mag. field(kG)	19.5	17.5
Proton max.(MeV)	84	400
Alpha max.(MeV)	130	400
^{3}He max.(MeV)	160	510
Weight of magnet(ton)	400	2100
Main coil magnet(kW)	450	440
No. of trim coils	16	36
Trim coil power(kW)	265	350
No. of cavities	1	3(Acc.) 1(FT)
RF frequency(MHz)	5.5~19.5	30~52 90~155
RF power(kW)	120	250×3 45

2. ACCELERATED BEAMS

300 MeV polarized and unpolarized proton beams are used for preliminary experiments with a high precision magnetic spectrograph and a neutron TOF facility. These beams are extracted with single turn extraction mode with flat-topping. The typical characteristics of the beam used for the experiments are shown in Table 3.

400 MeV protons, 400 MeV alpha particles and 200 MeV deuterons can not be injected properly now, depending insufficient performance of the deflector feed-through and the power supply of second magnetic inflection channel.

Proton beam was accelerated up to 400 MeV using abnormal setting of the injection elements. However the proton beam can not be extracted.

Table 3
Typical characteristics of the beam

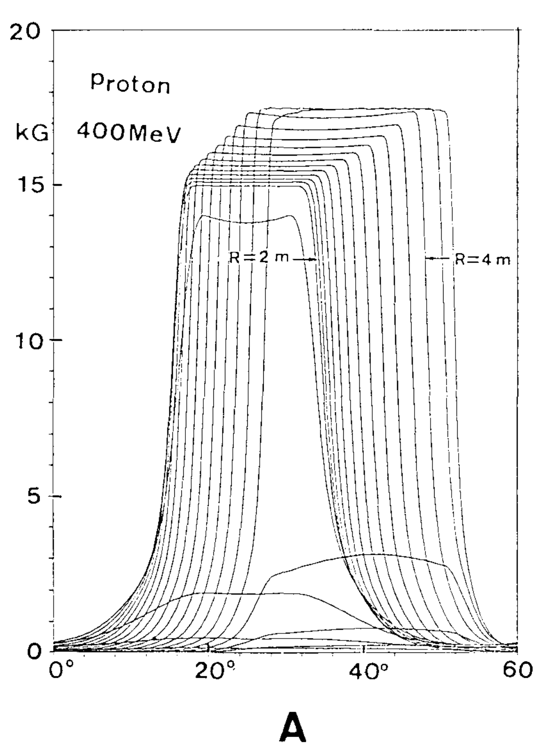
Injection beam	
Beam energy	53 MeV
Energy spread	~100 keV
Bunch length	20°(1000 ps)
Rad. emit.	2πmm mrad
Vert. emit.	2πmm mrad
Beam on target	
Beam energy	300 MeV
Energy spread	300 keV
Bunch length	10° (500 ps)
Rad. emit.	0.6π mm mrad
Vert. emit.	0.6π mm mrad
Unpolarized proton	20 nA
Polarized proton	5 nA

3. MAGNETS OF THE RING

The magnet of the six spiral sector ring cyclotron was designed by using computer code FIGER and the results of model magnet study of the previous proposal.[4] Figure 4 shows calculated field distribution with the code. The sector magnets are designed isochronous for 200 MeV proton acceleration without trim coil current. The measured magnetic field distribution are quite satisfactory.[5] Figure 5 shows comparison between betatron frequencies calculated from the measured magnetic field and the designed one. Figure 6 shows measured beam phase on predicted trim coil currents and optimized one for 300 MeV proton acceleration.

4. VACUUM SYSTEM

The vacuum chamber of the ring cyclotron consists of six magnet chambers, three acceleration cavity chambers, a flat-topping cavity chamber and two valley chambers as shown in Fig. 2. The gaps between these chambers are sealed by pneumatic expansion seals. These seals are working quite well.[6] The ring cyclotron is evacuated down to 1×10^{-7} Torr by six diffusion pumps with double chevron baffles (2,500ℓ/sec each eq.), three 16 inch cryopumps (6,500ℓ/sec each) with gate value and six 20 inch cryopumps (10,000ℓ/sec each).



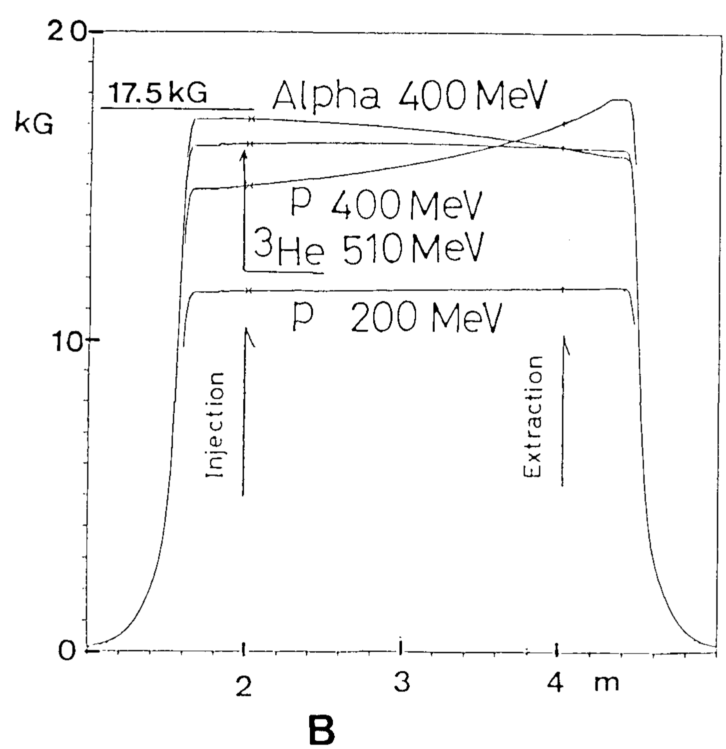


Fig. 4. A: Designed field distribution for 400 MeV proton.
B: Designed isochronous fields on hill center for various ions.

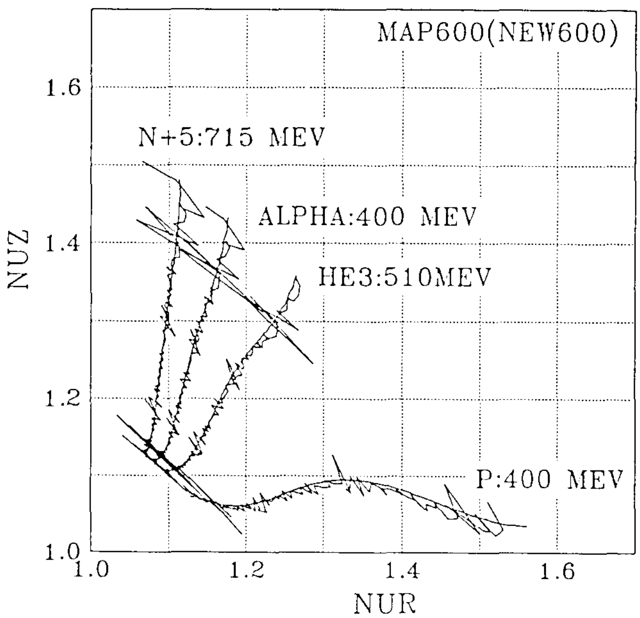


Fig. 5. Comparison between betatron frequencies calculated from the measured field and the designed one.

5. INJECTION AND EXTRACTION SYSTEM

The maximum designed parameters of the injection and extraction system are shown in Table 4. The injection and extraction system[7)] worked satisfactory as designed, for 300 MeV proton. However, voltage-holding capability of deflector feedthrough is not enough for 400 MeV proton acceleration. For acceleration of 400 MeV alpha particle, present 500A DC power supply of second magnetic inflection channel must be replaced by one of 700A.

Table 4. Parameters for 400 MeV beam

		Proton	α
Extraction	MeV	400.8	401.2
Injection	MeV	63.6	86.3
Rev. frequency	MHz	8.421	5.071
MIC1 ΔB	Gauss	+1730	+1889.3
MIC2 ΔB	Gauss	+550	+551.1
EIC1/EIC2	kV/cm	80	59.1
EEC1/EEC2	kV/cm	70	38
Electrode gap	cm	1	1
MEC1 ΔB	Gauss	-900	-759.3
MEC2 B	kGauss	10	9.187

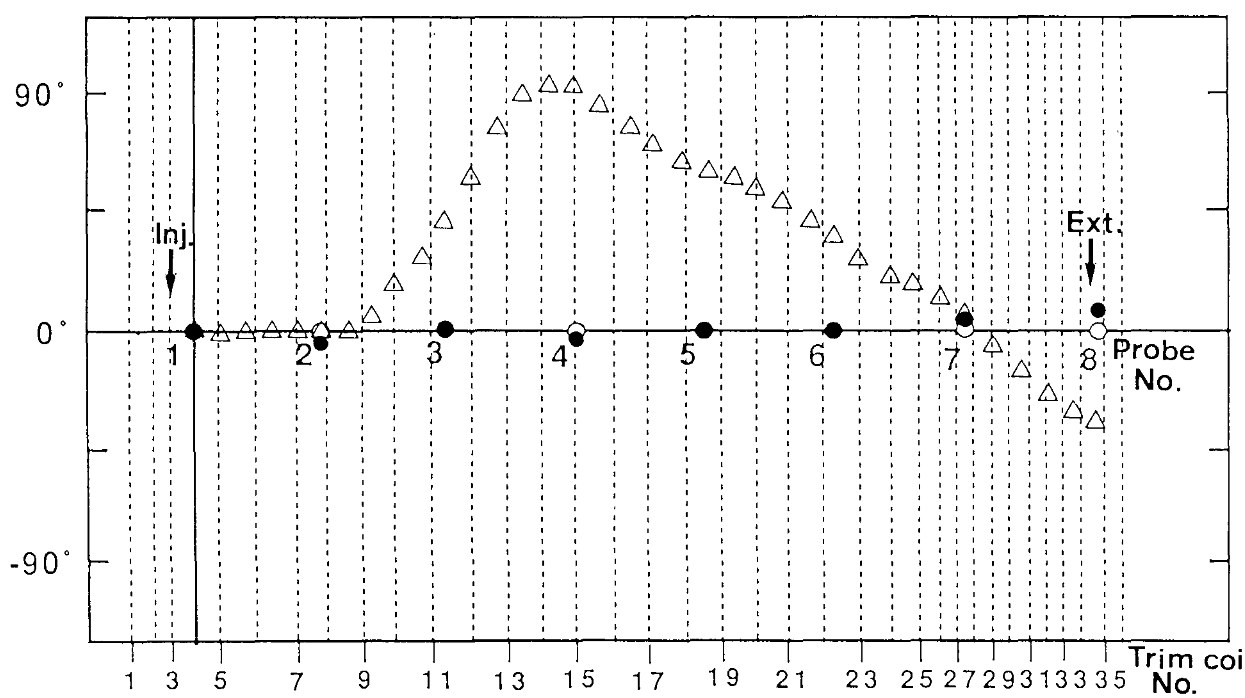


Fig. 6. Measured beam phase on predicted trim coil currents and optimized isochronous field, for 300 MeV proton acceleration.

6. ACCELERATION SYSTEM

The acceleration cavities, the flat-topping cavity and their RF power amplifiers were tested individually in 1990. The side walls of the cavity chamber can not withstand atmospheric pressure under evacuation, so these walls are supported by the magnet chambers. After full assembly of the ring cyclotron, full power test of the RF system and baking of the cavities were started.[8] The variable frequency acceleration cavity is tuned with a pair of rotatable plates. The resonant current on the rotatable plates flow through current-carrying hinges of thin copper plate and finger contact. The every finger-contact was replaced by newly designed one after initial trouble.

The RF power of the flat-topping cavity leaks easily to outside, for asymmetric setting of the sliding shorts. RF shields of trim coil feed-through were set on the both side of the flat-topping cavity.

Heterodyne method is used for the RF phase control system. Digital phase shifters, 0.03°/step, are working well on 455 kHz intermediate frequency. Stability of the acceleration voltage and phase will be improved in August.

7. AVF CYCLOTRON

Improvement of the injection beam of the ring cyclotron is also very important. A new beam phase selector for axial injection mode was developed as shown in Fig. 7. Efficient phase selection was made down to about 7°.

Upgrade of the injection beam characteristics, by using high intensity ion sources NEOMAFIOS and ECR ionizer, is expected in next year.

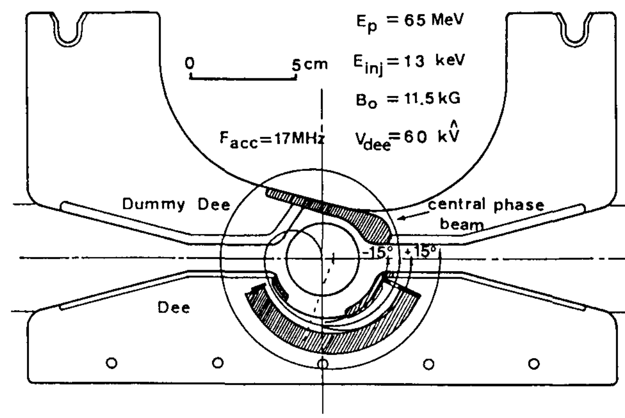


Fig. 7. Beam phase selector for axial injection mode of the AVF cyclotron.

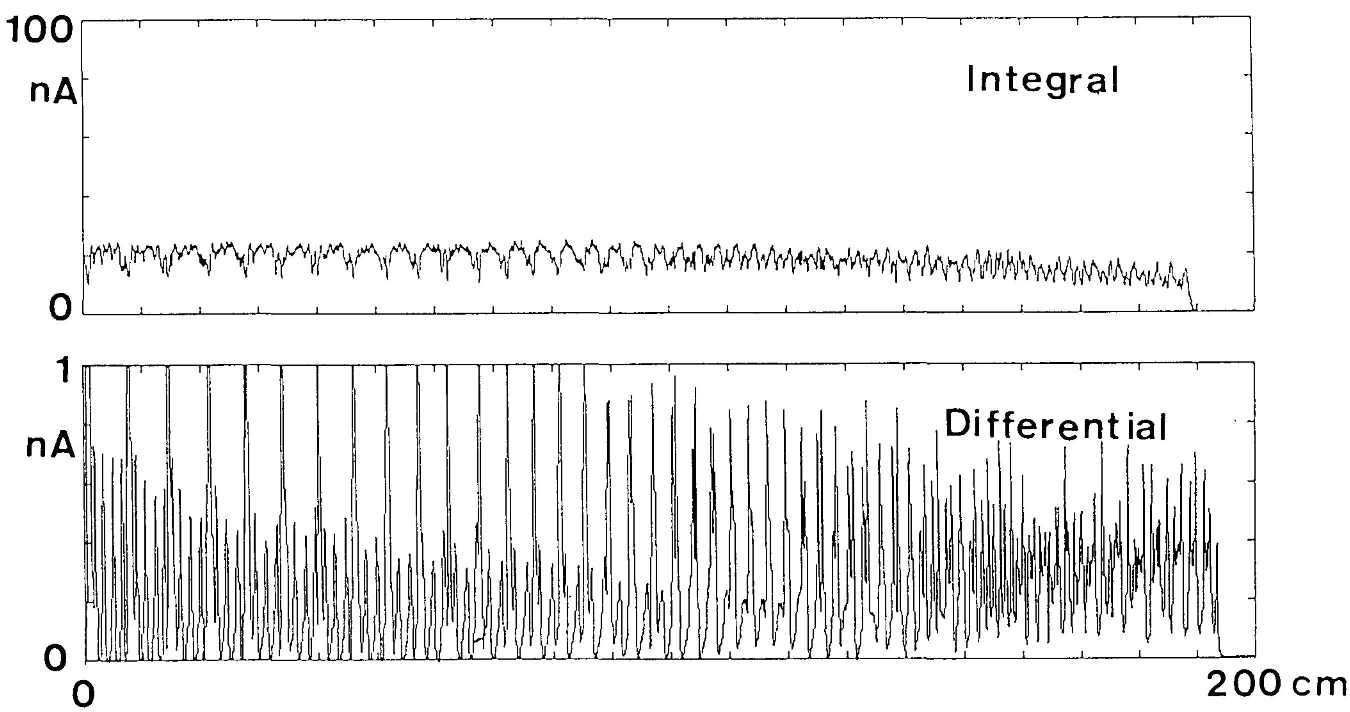


Fig. 8. Turn pattern measured by a main probe.

8. BEAM DIAGNOSTIC SYSTEM

The commissioning of the ring cyclotron is being made with various kind of beam diagnostic elements.[9] Efforts to get good S/N ratio for weak beam down to 1nA are being made. A 30 Hz 5th order (30dB/Oct) low pass filter is used for beam current measurement. Attenuation of 30dB for 60 Hz was achieved by using an integrated circuit of switched capacitor filter LTC1062. Figure 8 shows turn pattern measured by a main probe.

For beam phase measurement, noise-free phase signal amplifier for acceleration frequency was used. 5/3 and 8/5 multiple of the acceleration frequency are used for phase measurement of proton and alpha, respectively. A crystal filter is used in IF amplifier of the phase signal amplifier to reduce noise. The output signals are averaged by a digital oscilloscope to reduce thermal noise. Relative phase between beams can be measured with this phase probe for beam current down to 1nA, as shown in Fig. 9.

9. CONTROL SYSTEM

The old control system of the AVF cyclotron is used without any modification. New computer control system of the ring cyclotron was used throughout commissioning of the ring cyclotron.[10] The software of this control system performs almost satisfactory.

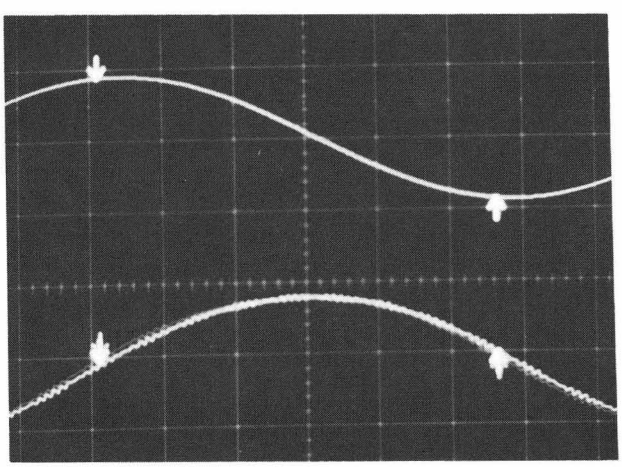


Fig. 9. Relative beam phase for few nA beams. Upper and lower correspond to pre-injection beam and pre-extraction beam, respectively. The IF phase signals are averaged by digital oscilloscope. 20°/div.

10. REFERENCES

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